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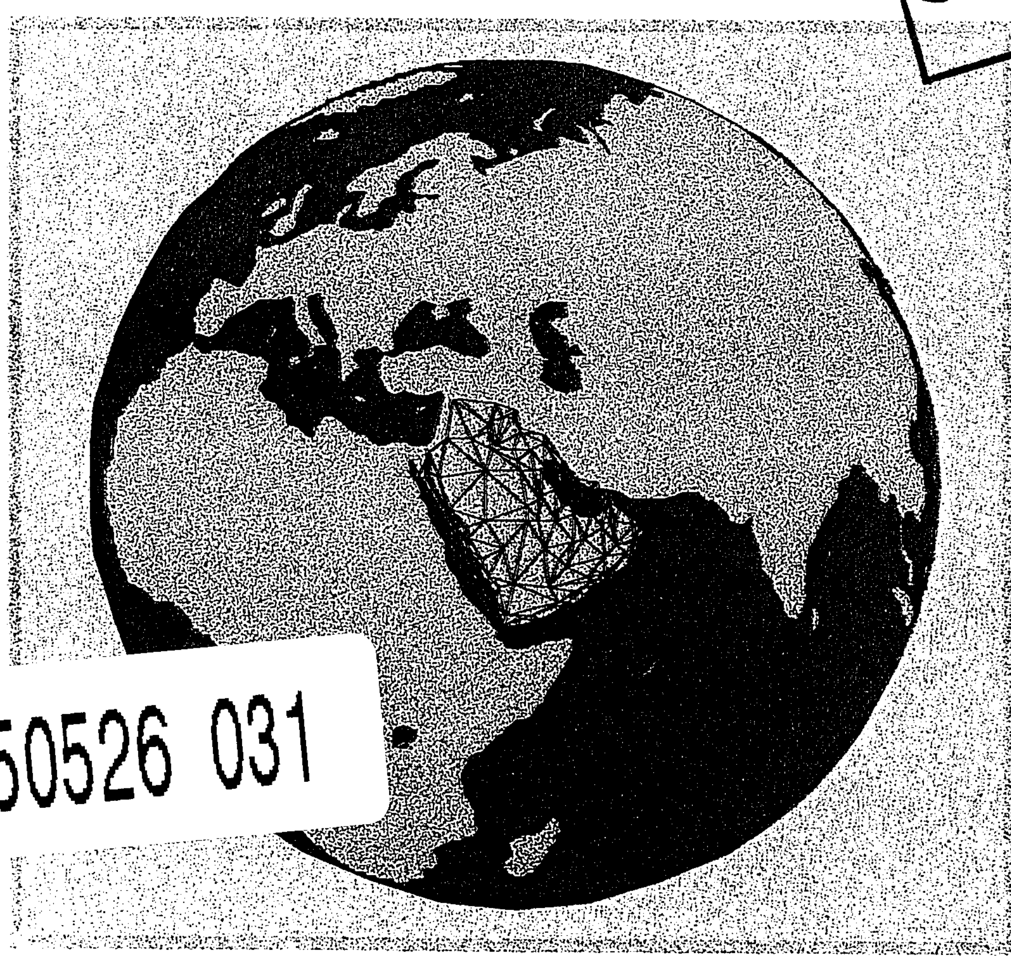

U.S. Army Communications-Electronics Command
Command, Control and Communications Systems Directorate
Fort Monmouth, New Jersey

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Tactical Line-of-Sight Path Reliability: Propagation Climate Factors

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Fort Monmouth, New Jersey 07703-5203

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The AirLand Operations warfighting concept requires reliable tactical communications worldwide. Achievement of reliable line-of-sight (LOS) radio communication links worldwide requires a propagation reliability model, including the effects of climate, for use in planning, engineering, and operation. The importance of propagation and climate has been demonstrated by recent experience in Southwest Asia. A CECOM LOS working group has developed a propagation reliability model, including a climate factor, that relates the reliability of an LOS radio link to path length, radio frequency, equipment capability, and geophysical and meteorological variables. Consequently, geophysical and meteorological variables for regions of any country can be included in the planning of tactical LOS communication links thereby helping achieve satisfactory propagation reliability. This report introduces a new application concept, monthly climate factors, since propagation reliability can vary significantly from month to month. In commercial practice, only annual or worst-month climate factors have been utilized. This report concentrates on the methodology by which monthly climate factors are developed which will provide coverage for regions of the world where climate factor information has not been available. Examples are given for Saudi Arabia, Germany and the U.S. The propagation reliability model has been incorporated into a new battlefield automated radio planning system, the Mobile Subscriber Equipment Network Planning Terminal.

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Abstract

The AirLand Operations warfighting concept requires reliable tactical communications worldwide. Achievement of satisfactory worldwide reliability of line-of-sight (LOS) radio communication links requires a propagation reliability model that includes the effects of climate in link planning, engineering, and operation. The importance of propagation and climate has been amply demonstrated by recent experience in Southwest Asia. A U.S. Army Communications-Electronics Command LOS working group has developed a propagation reliability model, including a climate factor, that relates the reliability of an LOS radio link to path length, radio frequency, equipment capability, and geophysical and meteorological variables. The climate factor can be calculated region by region for any country and should be included in the planning of tactical LOS communication links in order to help achieve satisfactory propagation reliability. Since propagation reliability can vary significantly from month to month, this report introduces a new application concept, monthly climate factors, to meet tactical needs. Previously, in commercial practice, only annual or worst-month climate factors have been utilized. This report concentrates on the methodology by which monthly climate factors are developed. The new methodology will provide coverage for regions of the world where climate factor information has not previously been available. Examples of methodology application are given for Saudi Arabia, Germany, and the U.S. The propagation reliability model, including the monthly climate factors, has been incorporated into a new battlefield automated radio planning system, the Mobile Subscriber Equipment Network Planning Terminal.

Executive Summary

The AirLand Operations warfighting concept requires reliable tactical communications worldwide. Achievement of satisfactory worldwide reliability of line-of-sight (LOS) radio communication links requires a propagation model that includes the effects of climate in link planning, engineering, and operation. The importance of propagation and climate has been amply demonstrated by recent experience in Southwest Asia. Programs to improve both the planning and engineering of Mobile Subscriber Equipment (MSE) networks and the propagation reliability of their LOS links are under way at the U.S. Army Communications-Electronics Command (CECOM) Command, Control and Communications Systems Directorate (C3SD).

A CECOM LOS working group has developed a propagation reliability model, including a climate factor, that relates the reliability of a LOS radio link to path length, radio frequency, equipment capability, and geophysical and meteorological variables (Reference 1). The model describes the transmission effects of the atmosphere on LOS links at tactical radio frequencies. Horizontal layers of differing humidity and temperature provide the mechanism for multiple rays from the transmitter to reach the receiving antenna. The received power during such multipath propagation varies rapidly in time (fades) because of the interference between the multiple rays. Outages occur when the received power fades deeper than the receiver threshold. The location of the receiver threshold on the fade depth scale is a function of equipment parameters, radio frequency, and path distance. The receiver threshold can correspond to fade depths ranging anywhere from a few dB to as high as 40 dB. Consequently, the propagation reliability model must cover a large range of fade depths.

Dependence on radio frequency and path distance has been analytically described by the propagation reliability model (Reference 1). The effects of the geophysical and meteorological variables are consolidated into an empirical coefficient, the climate factor, because analytical description of these effects is intractable. Values for the climate factor range from very small to about 100. Sample values have been determined from published long-term propagation fading measurements for various regions of the world. Meteorology, geophysical features, and temperature records are used computationally to estimate annual climate factors for geographic areas where propagation measurements have not been made.

Since the probability of fading at a particular location can vary significantly from month to month, this report introduces monthly climate factors as a new applications concept to meet tactical needs. Tactical LOS links are deployed for short periods of time, and their design must accommodate the climatic conditions for that time period. Utilization of worst-month probability of fading would frequently result in gross overdesign and waste of resources. Previously, in commercial practice, annual or worst-month climate factors have been utilized because commercial links are designed to be in service for many years. The climate factors pertain to the existence of horizontal atmospheric layers of differing humidity and temperature that vary with average monthly temperature. Operational experience indicates that the monthly climate factor is related to the monthly mean temperature. Fading can vary from insignificant at freezing temperatures to substantial at warm temperatures. There is monthly variation in the amount of fading even in climates where fading is present year-round. For example, there is monthly variation of fading near the Persian Gulf, where monthly

average temperatures vary by more than a factor of two. This report describes the method created by the CECOM LOS Propagation Reliability Working Group for obtaining monthly climate factors from available annual or worst-month climate factors. The new methodology can provide coverage for regions of the world where climate factor information has not previously been available.

The climate factor methodology has been applied to generate climate factors at a set of reference points. The locations of the reference points have been individually chosen based on geophysical features and the rate of change of the climate factor with respect to geographical position. The climate factor reference points, identified by latitude and longitude, are grouped in fixed triangles (reference triangles) for interpolation. Monthly average temperatures at a reference point are assumed to be those at the nearest of a worldwide set of weather stations, as measured by distance along a great circle. The source of the monthly temperature values is a world weather database (Reference 10). The report describes the development of reference annual climate factors, the triangle groupings, and the monthly average temperatures at reference points for test areas in Saudi Arabia and Germany. An example map showing the reference triangles and temperatures is also given for the U.S. and the Arabian peninsula.

The monthly climate factor for a tactical radio LOS link is determined by first specifying the coordinates of the link center. This point is within one of the reference triangles whose vertices are then identified. The monthly climate factors are calculated for each of the three reference points (triangle vertices) using the associated monthly temperatures. The monthly climate factor for the center of the link is then obtained by three-dimensional linear interpolation, using a plane defined by the three vertices.

The propagation reliability model has been incorporated in a new battlefield automated radio planning system, the MSE Network Planning Terminal (NPT). The NPT provides network planning, frequency management, and communications engineering capabilities. It has been developed for the Project Manager MSE and will be fielded in December 1992. The NPT has databases for annual climate factors at reference points, reference triangles, and average monthly temperatures. The NPT automatically provides the monthly climate factor for an LOS link using the methodology described in this report.

In conclusion, the climate factor modeling effort of the CECOM LOS Propagation Reliability Working Group has had both operational and research impact. Operationally, the Army now has a new capability for propagation reliability planning and engineering of tactical LOS communication links for deployment anywhere in the world. From a research standpoint, climate factor investigation has been stimulated as a result of the Army's tactical need for worldwide monthly climate factors.

Acknowledgments

The CECOM Line-of-Sight Propagation Reliability Working Group would like to recognize the continuing support of this work effort by the Office of the Project Manager, Mobile Subscriber Equipment; in particular, the involvement of A. W. Madnick, Deputy Project Manager, has resulted in an improved product. We have also benefited from the support and interest of the CECOM Research, Development and Engineering Center, especially that of J. J. Pucilowski, Jr., Director, Command, Control and Communications Systems, and R. E. Whitman, Deputy Director for Information Transport. Many technical interchanges with Dr. R. L. Olsen of the Canadian Government's Communications Research Centre have been invaluable. The review of a draft of this report by L. W. Goldberg, senior editor, CECOM R&D Technical Library, provided many helpful editorial suggestions.

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1. Introduction

Reliability of tactical line-of-sight (LOS) communications links has been shown to be sensitive to climate (References 1 and 2). This issue of link reliability has highlighted the tactical need to have reliable communications anywhere in the world.

Programs to improve both the planning and engineering of Mobile Subscriber Equipment (MSE) networks and the propagation reliability of their LOS links are under way at the U.S. Army Communications-Electronics Command (CECOM) Command, Control and Communications Systems Directorate (C3SD). The CECOM LOS Propagation Reliability Working Group has created an LOS propagation reliability model (Reference 1) and formulated improved operational procedures for LOS links in MSE (References 3 and 4). The improved communications engineering capability has been automated in the MSE Network Planning Terminal (NPT). Included in the NPT is the new capability for automatic calculation of the monthly climate factor for any tactical LOS link anywhere in the world. This report describes monthly climate factor development in the context of propagation reliability and the NPT.

2. Propagation Reliability Model

The propagation reliability model describes the transmission effects of the atmosphere on LOS links at tactical radio frequencies. Horizontal atmospheric layers of differing humidity and temperature abound in hot, flat coastal areas where dry desert air can interleave with moisture-saturated air from a large body of water. Conversely, propagation effects are minimal in northern mountainous areas where wind turbulence inhibits formation of layers and humidity is low.

The microwave index of refraction of the air becomes a nonlinear function of height above ground when the layers are present. Trajectories of rays from the transmitting antenna become distorted, with the result that multiple rays can reach the receiving antenna (Figure 2-1). The received power during such multipath propagation fluctuates (fades) because of mutual destructive interference of the rays (Figure 2-2). The fades can be deep enough to temporarily reduce the received power to practically zero. The sharp downward spikes in the fluctuations are the reason why a multipath (phase cancellation) model is invoked and why this type of fading is generally referred to as multipath fading.

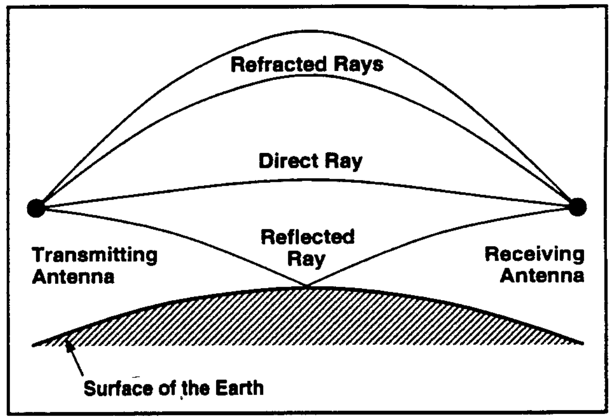

Figure 2-1. Multipath Propagation

The LOS propagation reliability model is based on an analytical representation of fading probability that is the fraction of time when a fade depth is exceeded (Refer-

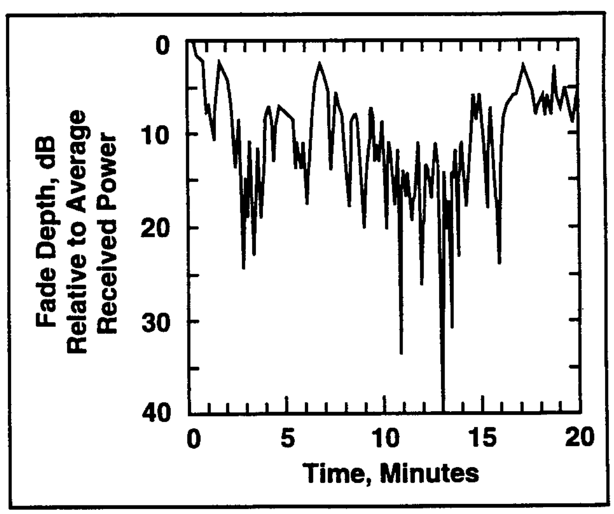

Figure 2-2. Multipath Fading

ence 1). The form and the parameter values of the fading probability distribution are based on theoretically derived functions and experimentally measured distributions. These distributions provide the real representation of multipath fading because they describe the total phenomenon that includes effects such as ducting (when the rays bend down) and ground-reflected components.

The fading probability is a function of the radio frequency, path distance, and geophysical and meteorological variables. The functional dependence on radio frequency and path distance has been analytically described (Reference 1). The effects of geophysical and meteorological variables are consolidated into an empirical coefficient, the climate factor, because purely analytical description of these effects is intractable. However, the various geophysical and meteorological effects are used to extend, by comparative analysis, the use of climate factors to regions where propagation measurements have not been made. The geophysical and meteorological variables pertain to the existence of horizontal atmospheric layers that create significant differences in the microwave index of refraction as a function of height. Layers of large horizontal extent form more easily over flat terrain than mountainous terrain, where wind turbulence inhibits layer formation. The difference in the microwave index of refraction between two layers increases as the difference in moisture content between the two layers increases. Proximity of a location to extended sources of moisture (large lakes, oceans) determines the moisture difference of layers. The differences are accentuated by temperature. This is why warm flat coastal areas are subject to intense multipath fading. At a given location, the presence of layering increases as the average monthly temperature increases. In addition to layer creation because of different directions of steady wind as a function of height (wind shear), there is also the effect of nocturnal radiation from the ground on nights with clear sky and little wind. This creates a ground-based layer of stable air referred to as a ground-based temperature-inversion layer. This confines humidity close to the surface. The result is a sharp negative gradient in the index of refraction as a function of height that causes multipath fading.

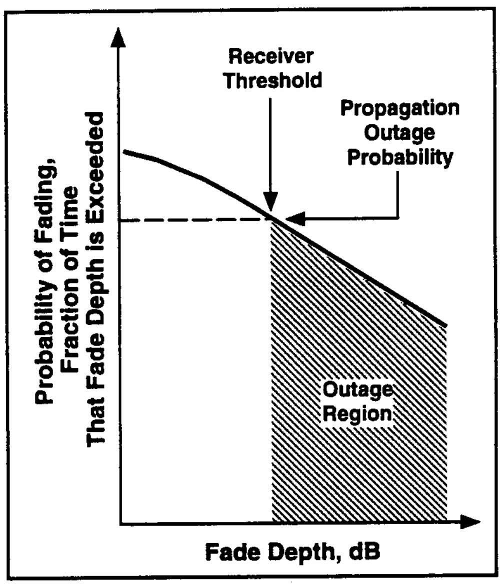

Figure 2-3. Fading and Outage

Outages occur when the received signal fades deeper than the receiver threshold (Figure 2-3). The location of the receiver threshold on the fade depth scale is a function of equipment parameters, radio frequency, and path distance. Consequently, the receiver threshold can correspond to fade depths ranging anywhere from a few dB to as high as 40 dB. This is why the propagation reliability model must cover an entire range of fade depths. Propagation reliability is the complement of propagation outage. As an example, a propagation outage of one percent corresponds to propagation reliability of 99 percent.

3. Climate Factor

The influence of climate on the probability of fading is described analytically by a parameter in the equations for the probability. This parameter, the climate factor, is defined and derived in this section. With no loss

of generality, the climate factor will be discussed in the context of fades exceeding 20 dB. However, the entire methodology is applicable for fades which exceed 0 dB.

3.1 Definitions

The climate factor is a parameter in the fading probability. For example, it appears as a coefficient (C) in the fading probability (P) for deep fades where P is much less than 100 percent. This is the probability that fading of the received power exceeds a particular fade depth (A)

$$P = C \times f(D, F, A), \quad A \geq 20 \text{ dB} \qquad (3\text{-}1)$$

where f is a function of path length (D), radio frequency (F), as well as A. The fade depth is expressed in positive dB relative to the average received power in the absence of fading. As a fade depth example, the received signal is said to be faded more than 20 dB (A = 20 dB) when its power is less than 0.01 of the average power in the absence of fading. The relationship of the parameters in Equation (3-1) is shown in the nomogram in Figure 3-1 (References 3 and 4). Equation (3-1) can be used as an approximation for fades as shallow as 10 dB, but the validity of the approximation must be established by comparing it to the fading probability in the shallow-fade region for the range of values of C of interest (Reference 1).

A logarithmic climate factor (G) has been used to describe fading in parts of Europe and Canada (References 5 and 6). The relationship of G to C is

$$G = 10 \log(C) + 5.8 \qquad (3\text{-}2)$$

The linkage between C and G has been established by equating fading probabilities at D = 40 km and F = 4 GHz since extensive experimental data is available at these values (Reference 1).

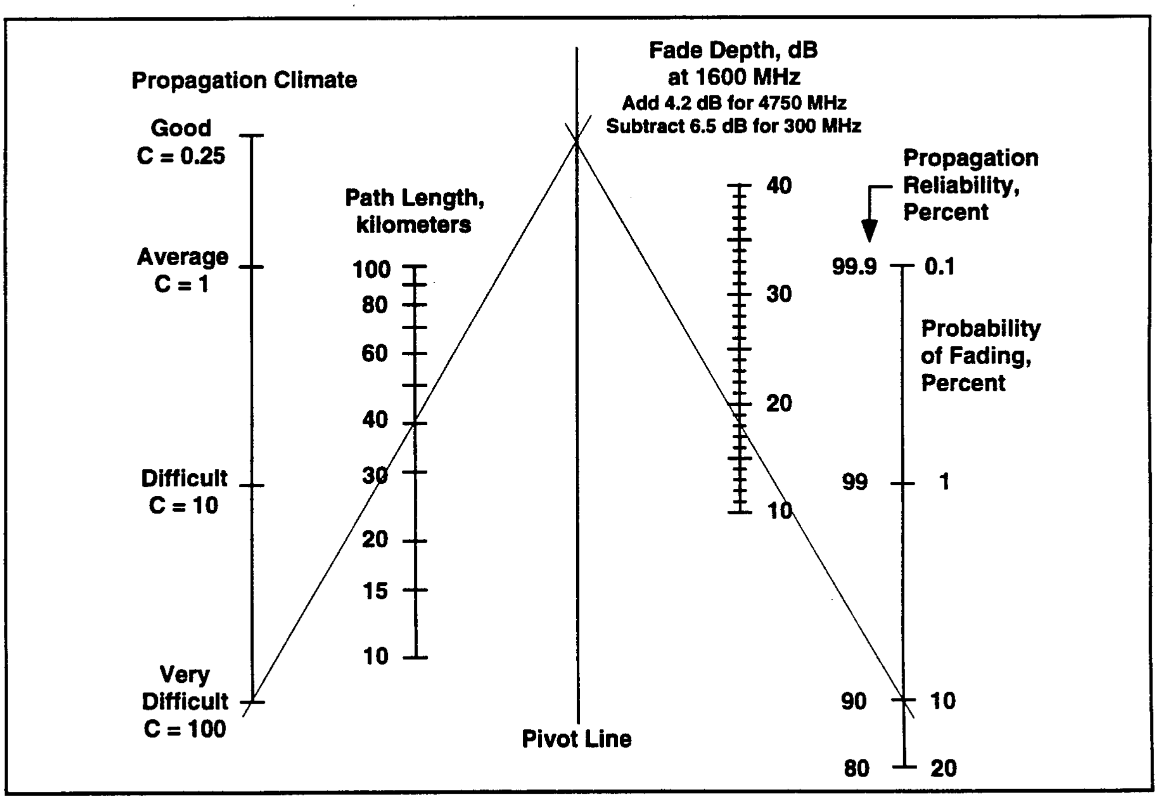

Figure 3-1. Multipath Fading Nomogram

Climate factors are generally obtained by fitting the equation for P to measured fading and then applying meteorological principles to extend applicability beyond the measurement location. The available climate factors in the literature are for annual probabilities (U.S. commercial practice) or worst-month probabilities (international practice).

Comparative meteorology, geophysical features, and temperature records are used to obtain annual climate factors for geographic areas where propagation measurements have not been made. This procedure is described later in this report.

3.2 Monthly Climate Factors

Monthly fading probability is needed for the communications engineering of tactical LOS links since the fading probability can vary significantly from month to month (Figure 3-2). Operational experience indicates that the monthly fading probability is related to the monthly mean temperature. Fading can vary from insignificant at freezing temperatures to substantial at warm temperatures. There is monthly variation in the amount of fading even in climates where fading is present year-round. For example, there is monthly variation of fading near the Persian Gulf where the difference of monthly average temperatures during a year is approximately 35 degrees Fahrenheit (Figure 3-3).

The CECOM LOS Propagation Reliability Working Group has devised a method for obtaining monthly climate factors from annual or worst-month climate factors. It is based on a weighting function (w) that is proportional to the average monthly temperature when this temperature is higher than a threshold value. The weighting function is zero when the average monthly temperature is below the threshold value. The corresponding zero monthly probability of fading in a winter month is acceptable in NPT because it simply invokes a design for a minimum fade depth margin of 8 dB for the link in question (References 1 and 3). If w_m denotes the value of the weighting for a month and $\langle w \rangle$ denotes the average of the 12 values of w_m for a year, then

$$C_m = (w_m / \langle w \rangle) \, C_a \qquad (3\text{-}3)$$

where C_m is the monthly climate factor and C_a is the

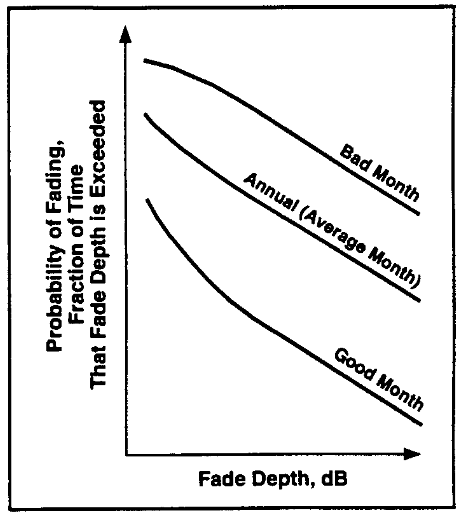

Figure 3-2. Monthly Fading Probability

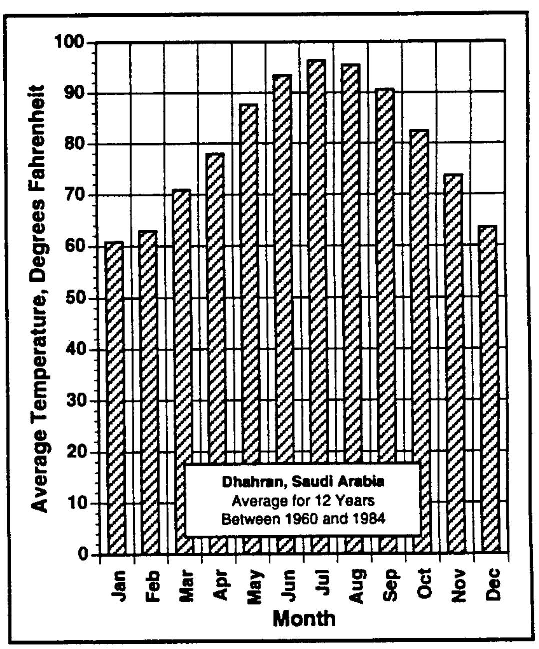

Figure 3-3. Monthly Temperature Example

annual climate factor. This provides the conversion from annual to monthly climate factors. The equation is inverted to obtain the annual climate factor when the worst-month climate factor is available. Equation (3-3) is then used to obtain the monthly climate factors.

The monthly climate factor definition in Equation (3-3) formalizes LOS link operational experience. An old rule of thumb for average links in the U.S. has been that all fading for a year can be assumed to be contained in two heavy fading months and two medium fading months with little fading for the rest of the year. Observations such as these have not been expanded and pursued in propagation research because commercial practice does not require monthly climate factors. The tactical need for monthly climate factors provides an impetus for new propagation research. Equation (3-3) can be viewed as the first step for such research.

To understand the role of the weighting function w_m, consider a hypothetical geographic location where the average monthly temperature is the same for each of the 12 months of the year. In this case

$$w_m = \langle w \rangle \qquad (3\text{-}4)$$

and the monthly climate factor is the same as the annual climate factor

$$C_m = C_a \qquad (3\text{-}5)$$

To further explore the effect of weighting functions, consider the mathematical description of the previously mentioned rule of thumb for an average link in the USA. Assume that heavy fading occurs in August and denote the corresponding weighting function by w_8. Further assume that fading in July is equally heavy ($w_7=w_8$). Assume that the probability of fading is smaller by a factor of two in the medium fading months of June and September ($w_6=0.5w_8$, $w_9=0.5w_8$). Then, assuming no fading in the other eight months,

$$\langle w \rangle = (1/12)\,(1+1+0.5+0.5)\,w_8 = (1/4)\,w_8 \qquad (3\text{-}6)$$

and the corresponding weighting ratio for August becomes

$$w_8/\langle w \rangle = 4 \qquad (3\text{-}7)$$

Note that multiplicative constants in the weighting function cancel when the ratio $w_m/\langle w \rangle$ is formed. This simplifies the formulation of the weighting function. The monthly climate factor for August becomes, using the previous equation,

$$C_8 = 4\,C_a \qquad (3\text{-}8)$$

This indicates that, in this example, the probability of deep fading in August is four times the annual probability of deep fading.

The formulation of the weighting function in this report is based upon two assumptions rooted in operational experience (Reference 7):

1. An increase of the monthly average temperature by 20 degrees Fahrenheit corresponds to a factor of five increase in the monthly climate factor.
2. The probability of fading is negligible when the average monthly temperature is smaller than 40 degrees Fahrenheit.

The mathematical expressions for the weighting function corresponding to these statements are

$$w_m = (1/4)\,(t_m - 40), \quad t_m \geq 40 \qquad (3\text{-}9)$$

$$w_m = 0, \quad t_m < 40 \qquad (3\text{-}10)$$

where t_m is the monthly average temperature in degrees Fahrenheit.

4. Climate Factor Methodology

This section describes the development procedure for generating annual climate factors at a set of reference points and the grouping of the reference points into a set of fixed triangles. The application of the methodology to test areas in Saudi Arabia and Germany is also described.

4.1 Climate Factor Reference Points

The climate-factor database contains information for the construction of a three-dimensional surface that describes the climate factor as a function of latitude and longitude. This surface is piece-wise linear, without any steps, and consists of triangular plane segments. It is constructed from vertex values of the triangles (reference points) and identification as to how the reference points are connected to form the triangles (reference triangles). The procedure for the generation of the reference points and the reference triangles contains the following general steps:

1. Draw line segments on a map to represent dominant constant-value contours for the climate factor. These contours follow geophysical features such as a set of mountain ridges, boundaries between plains and mountainous regions, boundaries and centers of major river basins, or boundaries of coastal areas of continents.
2. Assign values of annual climate factor to endpoints of the line segments in the controlling contours. These are the reference points in the climate factor database.
3. Assign additional reference points as needed to assure description of peaks, valleys, and flat areas of the climate factor surface.
4. Interconnect reference points with lines, orthogonal to the constant value lines if possible.
5. Add lines to subdivide areas that have more than three sides. Use the shorter of the two diagonals when subdividing a four-sided area.

Two examples in the subsequent sections illustrate this procedure. The examples are for rectangular areas in Saudi Arabia and Germany that were used for NPT software trials.

4.2 Development for Saudi Arabia

The Saudi Arabia development example is a rectangle that covers five degrees of latitude and eight degrees of longitude (Figure 4-1). Climate factors for this rectangle were provided for software testing of NPT.

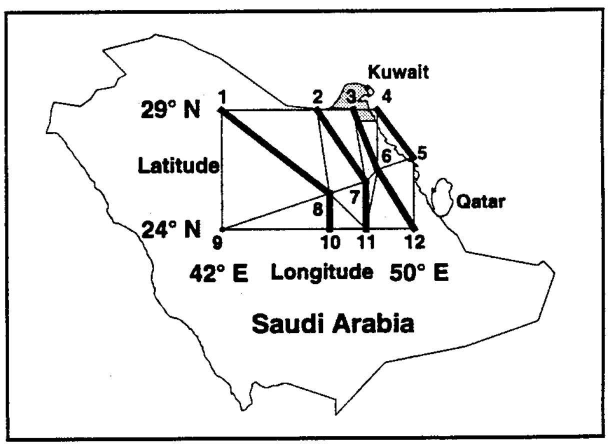

Figure 4-1. Saudi Arabia Development Example Area

The controlling constant-value contours for the climate factor in this example are determined by the distance from the Persian Gulf and by ground elevation. The climate factor is constant along the shoreline, represented by the line 4-5 in Figure 4-1. Representation of the shoreline by such line segments simplifies construction of the climate-factor surface. The constant-value line seg-

ments 3-6-12 and 2-7-11 follow elevation contours and describe transition from coastal to interior climate. The constant-value line segments 1-8-10 describe the interior climate. Point 9 is added to complete the rectangle.

The annual climate factor values for the coastal points 4 and 5 are obtained from world contours of refractivity gradients (Reference 8), since published values of the climate factors are not available. Fading in the coastal areas of the Persian Gulf peaks in late summer, when ducting gradients of the index of refraction are present 70 percent of the time (Figure 4-2a). Ducting gradients in a similar atmospheric regime in Florida are present five percent of the time (Figure 4-2b). The probability of fading in the coastal area of the Persian Gulf is therefore approximately 14 times higher than that in Florida (the ratio of 70 to 5). The annual climate factor for central Florida is six, which translates to annual climate factor values of 85 for the Saudi Arabia reference points 4 and 5. This conforms to general knowledge in the line-of-sight engineering community that fading near the Persian Gulf is at least an order of magnitude more intense than that in Florida.

An annual climate factor of two is assigned to the interior reference points 1, 8, 9, and 10. This is based on Reference 9, but with an additional factor of two included to allow for signal depressions due to ducting.

The annual climate factor values assigned in the transition region are 50 (for points 3, 6, and 12) and 10 (for points 2, 7, and 11). These assignments are based on previous engineering experience with climate factor maps.

Formation of the reference triangles begins with the drawing of the line segments 5-6-7-8-9 that are approximately orthogonal to the constant-value segments. A set of polygons is obtained when the boundary lines for the rectangular area are drawn. These are subdivided to obtain triangles. For example, line 2-8 is drawn to subdivide the polygon 1-2-7-8. Line 2-8 is chosen because it is the shorter of the two diagonals.

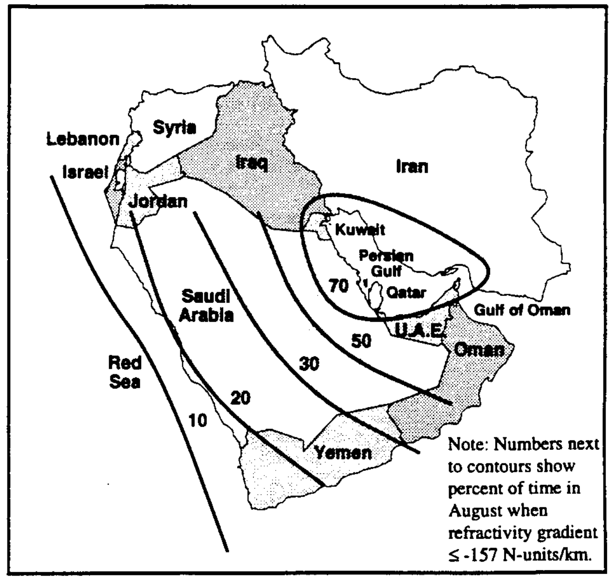

Figure 4-2a. Persian Gulf Refractivity Gradient Contours

Monthly climate factors for application in NPT are obtained from the annual climate factors by temperature weighting as described in Section 3.2. The weather station locations in the development example that have recorded data for ten-or-more years are shown in Figure 4-3 (Reference 10). Each weather station is identified by its World Meteorological Organization (WMO) number. The loca-

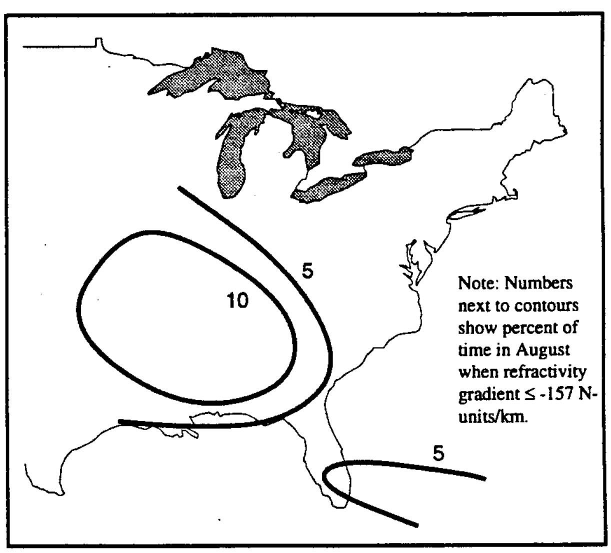

Figure 4-2b. U.S. Refractivity Gradient Contours

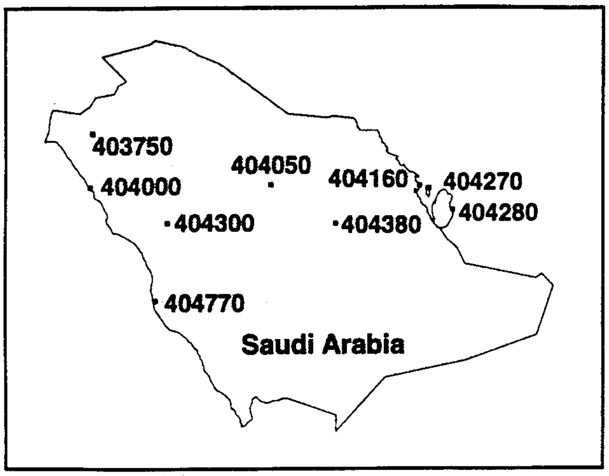

Figure 4-3. Saudi Arabia Weather Stations

tion names associated with the WMO numbers are listed in Table 4-1. Monthly average temperatures for a reference point are obtained from the weather station nearest to it, measured by a great-circle distance. The results are shown in Table 4-2, which contains the reference point number, the coordinates of the reference point, the annual climate factor, the WMO number of the associated weather station, and the 12 average monthly temperatures. The corresponding values of the monthly climate factors are shown in Table 4-3 for reference point 1 (interior of Saudi Arabia) and reference point 5 (coastal area of Persian Gulf). Note the monthly climate factor spread from 120.7 for July on the coast to 1.11 in January in the interior.

Information about the triangles is contained in the NPT database in the form of the coordinates of the three vertices of each triangle. This is illustrated in Table 4-4 for the triangles in the Saudi Arabia development example.

4.3 Development for Germany

The Germany development example is a rectangle that covers four degrees of latitude and nine degrees of longitude (Figure 4-4). This contains southern Germany and parts of surrounding countries. The presence of mountains, river valleys, and relatively flat areas results in a complicated set of climate-factor contours. Four of the dominant constant-value contours are drawn as heavy line segments in Figure 4-4. The annual climate factor in the rectangle is between 0.01 and 0.5 (from Reference 9). The heavy contour in the upper left-hand corner identifies the Rhine river valley. The value of the annual climate factor along this contour is 0.4. The heavy contour on bottom right is along mountain ridges in Austria. The annual climate factor on this contour is 0.01. The heavy contour in the upper-right-hand corner identifies a valley near Prague. The annual climate factor on the contour is 0.2. The heavy contour near the border of Germany and Czechoslovakia identifies a hilly region. The annual climate factor on this contour is 0.05.

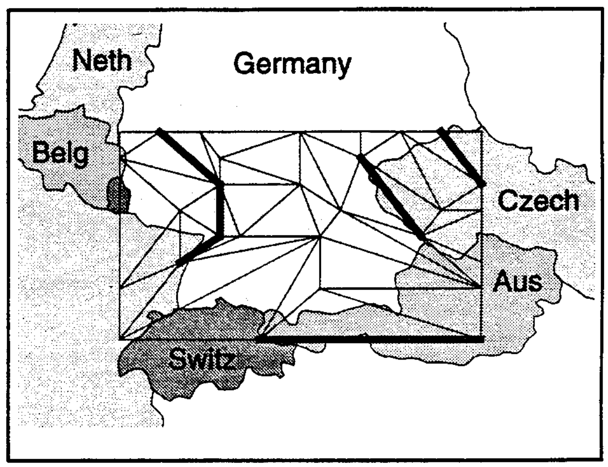

Figure 4-4. Germany Development Example Area

The locations of German weather stations are shown in Figure 4-5. The WMO numbers are associated with weather-station names in Table 4-5. The results for the reference points are listed in Table 4-6.

5. Climate Factor Product Examples

Climate factor coverage for the Arabian peninsula and for the United States provides examples of the product contained in NPT. The coverage is shown in terms of the reference points and the associated triangles.

Table 4-1. Saudi Arabia Weather Station Locations

WMO Number	City	Latitude Deg. N	Longitude Deg. E
403750	Tabouk	28.40	36.60
404000	Wejh	26.20	36.50
404050	Khassim	26.30	44.00
404160	Dhahran	26.30	50.20
404270	Bahrain	26.20	50.60
404280	Doha	25.30	51.60
404300	Medina	24.70	39.70
404380	Riyadh	24.70	46.70
404770	Jeddah	21.50	39.20

Table 4-3. Saudi Arabia Monthly Climate Factor Development

Month	Reference Point	
	1 29.00 Deg.N 42.00 Deg. E WMO 404300 Annual C: 2.00	5 27.00 Deg. N 50.00 Deg. E WMO 404160 Annual C: 85.00
JAN	1.11	44.73
FEB	1.36	49.14
MAR	1.67	66.26
APR	1.99	81.50
MAY	2.35	102.26
JUN	2.66	114.61
JUL	2.67	120.70
AUG	2.64	118.33
SEP	2.55	108.45
OCT	2.11	91.11
NOV	1.63	71.99
DEC	1.26	50.43

Table 4-2. Database for Saudi Arabia Rectangle (Monthly Average Temperatures in Degrees Fahrenheit)

Ref. Point	Lat. Deg. N	Long. Deg. E	Annual C	WMO Number	JAN Avg	FEB Avg	MAR Avg	APR Avg	MAY Avg	JUN Avg	JUL Avg	AUG Avg	SEP Avg	OCT Avg	NOV Avg	DEC Avg
1	29.00	42.00	2.00	404300	63.58	68.87	75.44	82.39	89.90	96.62	96.69	96.16	94.25	84.89	74.70	66.75
2	29.00	46.00	10.00	404380	57.30	61.39	69.99	77.44	88.01	92.57	94.45	93.73	89.06	78.62	69.17	59.35
3	29.00	47.50	50.00	404160	60.81	62.87	70.84	77.93	87.59	93.34	96.17	95.30	90.47	82.40	73.50	63.47
4	29.00	48.50	85.00	404160	60.81	62.87	70.84	77.93	87.59	93.34	96.17	95.30	90.47	82.40	73.50	63.47
5	27.00	50.00	85.00	404160	60.81	62.87	70.84	77.93	87.59	93.34	96.17	95.30	90.47	82.40	73.50	63.47
6	26.50	48.50	50.00	404160	60.81	62.87	70.84	77.93	87.59	93.34	96.17	95.30	90.47	82.40	73.50	63.47
7	26.00	48.00	10.00	404380	57.30	61.39	69.99	77.44	88.01	92.57	94.45	93.73	89.06	78.62	69.17	59.35
8	25.50	46.50	2.00	404380	57.30	61.39	69.99	77.44	88.01	92.57	94.45	93.73	89.06	78.62	69.17	59.35
9	24.00	42.00	2.00	404300	63.58	68.87	75.44	82.39	89.90	96.62	96.69	96.16	94.25	84.89	74.70	66.75
10	24.00	46.50	2.00	404380	57.30	61.39	69.99	77.44	88.01	92.57	94.45	93.73	89.06	78.62	69.17	59.35
11	24.00	48.00	10.00	404380	57.30	61.39	69.99	77.44	88.01	92.57	94.45	93.73	89.06	78.62	69.17	59.35
12	24.00	50.00	50.00	404280	63.08	64.63	70.79	78.17	87.33	92.78	94.29	93.34	89.82	83.93	75.41	66.36

Table 4-4. Saudi Test Area Triangle Coordinates

Triangle Vertices	Latitude 1 Deg. N	Longitude 1 Deg. E	Latitude 2 Deg. N	Longitude 2 Deg. E	Latitude 3 Deg. N	Longitude 3 Deg. E
1-2-8	29.00	42.00	29.00	46.00	25.50	46.50
2-7-8	29.00	46.00	26.00	48.00	25.50	46.50
2-3-7	29.00	46.00	29.00	47.50	26.00	48.00
3-6-7	29.00	47.50	26.50	48.50	26.00	48.00
3-4-6	29.00	47.50	29.00	48.50	26.50	48.50
4-5-6	29.00	48.50	27.00	50.00	26.50	48.50
5-6-12	27.00	50.00	26.50	48.50	24.00	50.00
6-11-12	26.50	48.50	24.00	48.00	24.00	50.00
6-7-11	26.50	48.50	26.00	48.00	24.00	48.00
7-8-11	26.00	48.00	25.50	46.50	24.00	48.00
8-10-11	25.50	46.50	24.00	46.50	24.00	48.00
8-9-10	25.50	46.50	24.00	42.00	24.00	46.50
1-8-9	29.00	42.00	25.50	46.50	24.00	42.00

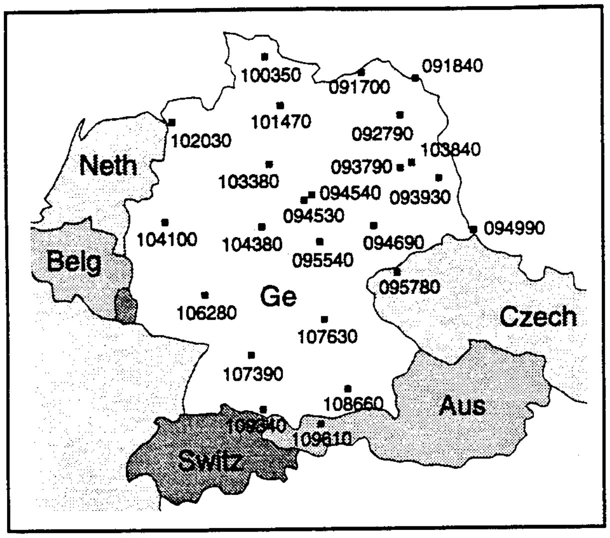

Figure 4-5. Germany Weather Stations

Table 4-5. Germany Weather Stations

WMO Number	City	Latitude Deg. N	Longitude Deg. E
091700	Warnemunde	54.20	12.10
091840	Griefswald/Wieck	54.10	13.50
092790	Neustrelitz	53.40	13.10
093790	Potsdam	52.40	13.10
093930	Lindengerg	52.20	14.10
094530	Brocken	51.80	10.60
094540	Wernigerode	51.90	10.80
094690	Leipzig	51.30	12.40
094990	Gorlitz	51.20	15.00
095540	Erfurt/Bindersleben	51.00	11.00
095780	Fichtelberg	50.40	13.00
100350	Schleswig	54.50	9.60
101470	Hamburg/Fuhlsbuttel	53.60	10.00
102030	Emden-Wolthusen	53.30	7.20
103380	Hannover	52.50	9.70
103840	Berlin/Tempelhof	52.50	13.40
104100	Essen	51.40	7.00
104380	Kassel	51.30	9.50
106280	Geisenheim	50.00	8.00
107390	Stuttgart/Cannstadt	48.80	9.20
107630	Nurnberg	49.50	11.10
108660	Munchen/Riem	48.10	11.70
109340	Friedrichshafen	47.70	9.50
109610	Zugspitze	47.40	11.00

Table 4-6. Database for Germany Rectangle
(Monthly Average Temperatures in Degrees Fahrenheit)

Ref. Point	Lat. Deg. N	Long. Deg. E	Annual C	WMO Number	JAN Avg	FEB Avg	MAR Avg	APR Avg	MAY Avg	JUN Avg	JUL Avg	AUG Avg	SEP Avg	OCT Avg	NOV Avg	DEC Avg
1	51.00	6.00	0.20	104100	34.75	36.01	40.90	47.35	54.85	60.36	63.11	62.64	57.94	50.98	42.38	36.92
2	51.00	7.00	0.40	104100	34.75	36.01	40.90	47.35	54.85	60.36	63.11	62.64	57.94	50.98	42.38	36.92
3	51.00	8.00	0.10	104100	34.75	36.01	40.90	47.35	54.85	60.36	63.11	62.64	57.94	50.98	42.38	36.92
4	51.00	10.50	0.10	095540	28.73	31.11	36.72	44.64	52.92	59.17	61.80	61.35	56.10	47.54	38.46	31.90
5	51.00	12.00	0.20	094690	30.23	32.50	38.25	46.22	54.75	61.36	63.84	63.43	57.62	49.14	40.20	33.61
6	51.00	13.00	0.10	094690	30.23	32.50	38.25	46.22	54.75	61.36	63.84	63.43	57.62	49.14	40.20	33.61
7	51.00	14.00	0.20	094990	28.01	31.05	37.21	45.26	54.10	60.61	62.82	62.25	56.46	48.28	39.28	32.12
8	51.00	15.00	0.10	094990	28.01	31.05	37.21	45.26	54.10	60.61	62.82	62.25	56.46	48.28	39.28	32.12
9	50.50	6.00	0.10	104100	34.75	36.01	40.90	47.35	54.85	60.36	63.11	62.64	57.94	50.98	42.38	36.92
10	50.50	8.50	0.20	106280	33.54	36.05	41.96	49.25	56.51	62.66	65.32	64.26	58.63	49.79	41.33	35.70
11	50.50	12.00	0.05	095780	21.88	23.30	27.29	33.74	43.41	49.05	52.29	51.93	46.83	39.71	30.05	25.19
12	50.00	8.50	0.40	106280	33.54	36.05	41.96	49.25	56.51	62.66	65.32	64.26	58.63	49.79	41.33	35.70
13	50.00	10.50	0.20	107630	30.05	32.30	38.80	46.74	55.35	61.92	64.78	63.29	57.07	48.00	39.21	32.78
14	50.00	15.00	0.20	094990	28.01	31.05	37.21	45.26	54.10	60.61	62.82	62.25	56.46	48.28	39.28	32.12
15	49.50	7.50	0.10	106280	33.54	36.05	41.96	49.25	56.51	62.66	65.32	64.26	58.63	49.79	41.33	35.70
16	49.50	11.50	0.10	107630	30.05	32.30	38.80	46.74	55.35	61.92	64.78	63.29	57.07	48.00	39.21	32.78
17	49.50	14.00	0.10	095780	21.88	23.30	27.29	33.74	43.41	49.05	52.29	51.93	46.83	39.71	30.05	25.19
18	49.50	15.00	0.10	095780	21.88	23.30	27.29	33.74	43.41	49.05	52.29	51.93	46.83	39.71	30.05	25.19
19	49.00	8.50	0.40	107390	32.39	34.78	41.06	48.05	55.37	61.49	65.08	63.84	58.59	49.77	40.63	34.49
20	49.00	9.00	0.20	107390	32.39	34.78	41.06	48.05	55.37	61.49	65.08	63.84	58.59	49.77	40.63	34.49
21	49.00	11.00	0.05	107630	30.05	32.30	38.80	46.74	55.35	61.92	64.78	63.29	57.07	48.00	39.21	32.78
22	49.00	13.50	0.05	095780	21.88	23.30	27.29	33.74	43.41	49.05	52.29	51.93	46.83	39.71	30.05	25.19
23	48.50	7.50	0.40	107390	32.39	34.78	41.06	48.05	55.37	61.49	65.08	63.84	58.59	49.77	40.63	34.49
24	48.50	15.00	0.05	108660	28.56	30.73	37.70	45.46	53.61	59.86	63.23	61.94	56.53	47.13	37.98	30.98
25	48.00	6.00	0.10	107390	32.39	34.78	41.06	48.05	55.37	61.49	65.08	63.84	58.59	49.77	40.63	34.49
26	48.00	11.00	0.10	108660	28.56	30.73	37.70	45.46	53.61	59.86	63.23	61.94	56.53	47.13	37.98	30.98
27	48.00	15.00	0.10	108660	28.56	30.73	37.70	45.46	53.61	59.86	63.23	61.94	56.53	47.13	37.98	30.98
28	47.00	6.00	0.05	109340	31.72	34.59	39.46	47.64	55.56	61.70	65.14	64.01	58.36	48.74	40.62	32.47
29	47.00	9.50	0.01	109340	31.72	34.59	39.46	47.64	55.56	61.70	65.14	64.01	58.36	48.74	40.62	32.47
30	47.00	15.00	0.01	108660	28.56	30.73	37.70	45.46	53.61	59.86	63.23	61.94	56.53	47.13	37.98	30.98

5.1 Arabian Peninsula

The reference points and the triangles for the Arabian peninsula are shown in Figure 5-1. Locations of weather stations that have recorded four-or-more years of data are shown in Figure 5-2. The WMO numbers are associated with location names in Table 5-1. Weather information is scarce in this part of the world. The weather stations are far apart in some regions. As few as four years had to be used in some of the temperature averages.

Table 5-1. Middle East Weather Stations

WMO Number	City	Latitude Deg. N	Longitude Deg. E
400010	Kamishli, Syria	37.10	41.20
400070	Aleppo, Syria	36.20	37.20
400220	Lattakia, Syria	35.60	35.80
400450	Deir Ezzor, Syria	35.30	40.20
400610	Palmyra, Syria	34.60	38.30
400800	Damascus/Mezee, Syria	33.50	36.20
401800	Lod Airport, Israel	32.00	34.90
401840	Jerusalem, Israel	31.80	35.20
402500	H-4, Jordan	32.50	38.20
402700	Amman Airport, Jordan	32.00	35.90
402900	Jordan	31.90	35.20
403100	Ma'An, Jordan	30.20	35.80
403750	Tabouk, Saudi Arabia	28.40	36.60
404000	Wejh, Saudi Arabia	26.20	36.50
404050	Khassim, Saudi Arabia	26.30	44.00
404160	Dhahran, Saudi Arabia	26.30	50.20
404270	Bahrain, Saudi Arabia	26.20	50.60
404280	Doha Qatar, Saudi Arabia	25.30	51.60
404300	Medina, Saudi Arabia	24.70	39.70
404380	Riyadh, Saudi Arabia	24.70	46.70
404600	Muscat, Saudi Arabia	23.60	58.60
404770	Jeddah, Saudi Arabia	21.50	39.20
405970	Aden, Yemen	12.80	45.10
406080	Mosul, Iraq	36.30	43.20
406210	Kirkuk, Iraq	35.50	44.40
406420	Rutbah, Iraq	33.00	40.30
406480	Habbaniya, Iraq	33.40	43.60
406500	Baghdad, Iraq	33.30	44.40
406650	Kut-El-Hai, Iraq	32.20	46.10
406700	Najaf, Iraq	32.00	44.30
406720	Diwaniya, Iraq	32.00	45.00
406760	Nasiriya, Iraq	31.00	46.20
406890	Basrah, Iraq	30.40	47.70
407060	Tabriz, Iran	38.10	46.30
407450	Mashhad, Iran	36.30	59.60
407540	Tehran-Mehrabad, Iran	35.70	51.40
408000	Esfahan, Iran	32.70	51.70
408310	Abadan, Iran	30.40	48.30
408410	Kerman, Iran	30.30	57.00
408460	Bushehr, Iran	29.00	50.80
408480	Shiraz, Iran	29.60	52.50

The triangles are smaller in the coastal areas than in the interior because the propagation climate changes more rapidly as a function of location in the coastal areas. Propagation in the narrow coastal strip along the Red Sea is as difficult as that along the Persian Gulf. This is based on operational experience known in the line-of-sight communications engineering community. This knowledge was used in addition to information obtained from maps of refractivity gradient contours. The important point here is that engineering information and judgment must be used in the creation of the climate factor database.

5.2 United States

The U.S. reference points and triangles are shown in Figure 5-3. Locations of weather stations are shown in Figure 5-4. The WMO numbers are associated with location names in Table 5-2. The monthly temperatures for each of these weather stations are based on at least 15 years of data.

The triangles are smaller in Florida, along the Gulf Coast, along the Mississippi, and in Southern California. Propagation is worse than average in these areas, and the climate factor there changes relatively rapidly with location. The triangles around the Great Lakes highlight the fact that propagation there is also worse than average. Source material for the values of the annual climate factor is Reference 8, with modifications based on engineering experience.

6. Network Planning Terminal

The NPT provides network planning, frequency management, and communications engineering capabilities. It is being jointly developed for the Project Manager MSE by the Electromagnetic Compatibility Analysis Center (ECAC) and CECOM for fielding in December 1992. A major new capability of the NPT is the Com-

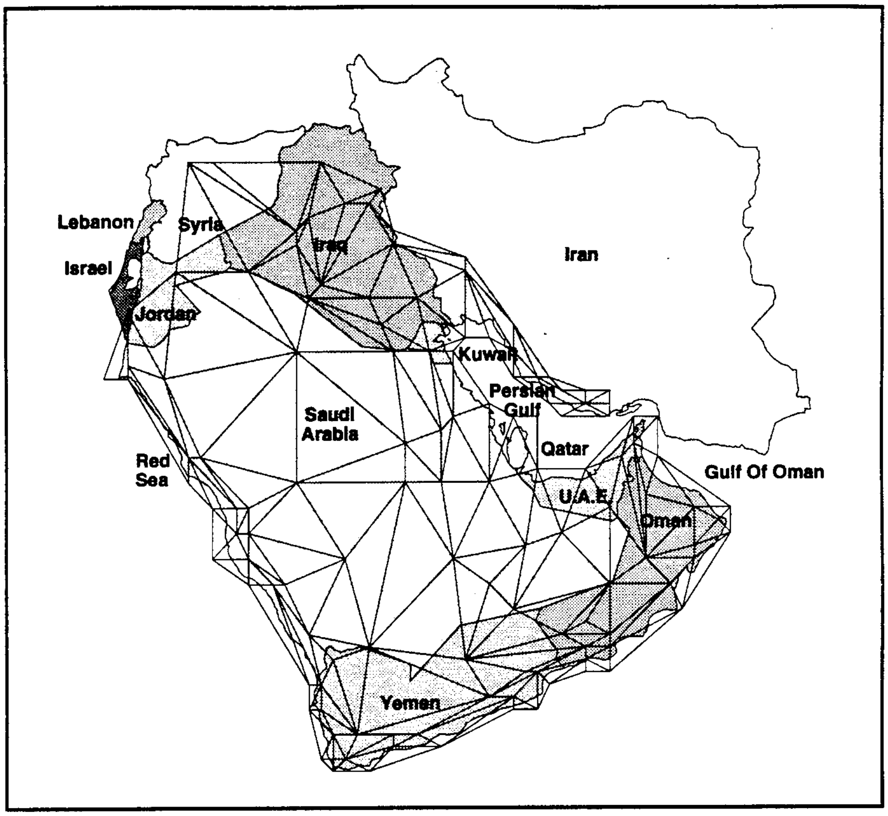

Figure 5-1. Middle East Triangles Based on Reference Points

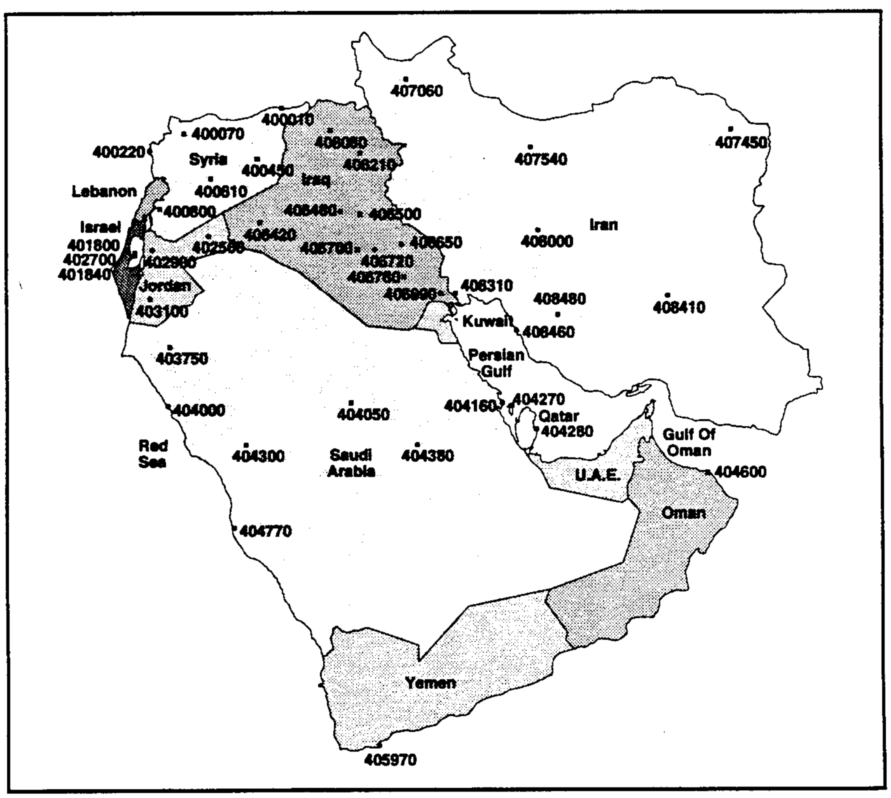

Figure 5-2. Middle East Weather Stations

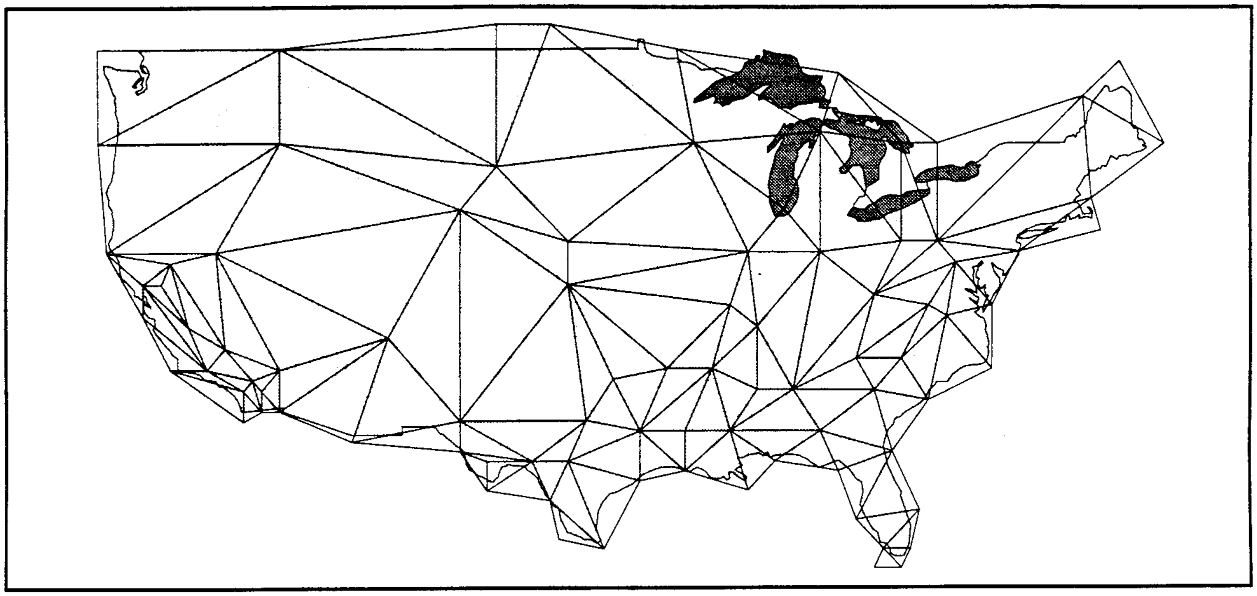

Figure 5-3. Continental U.S. Triangles Based on Reference Points

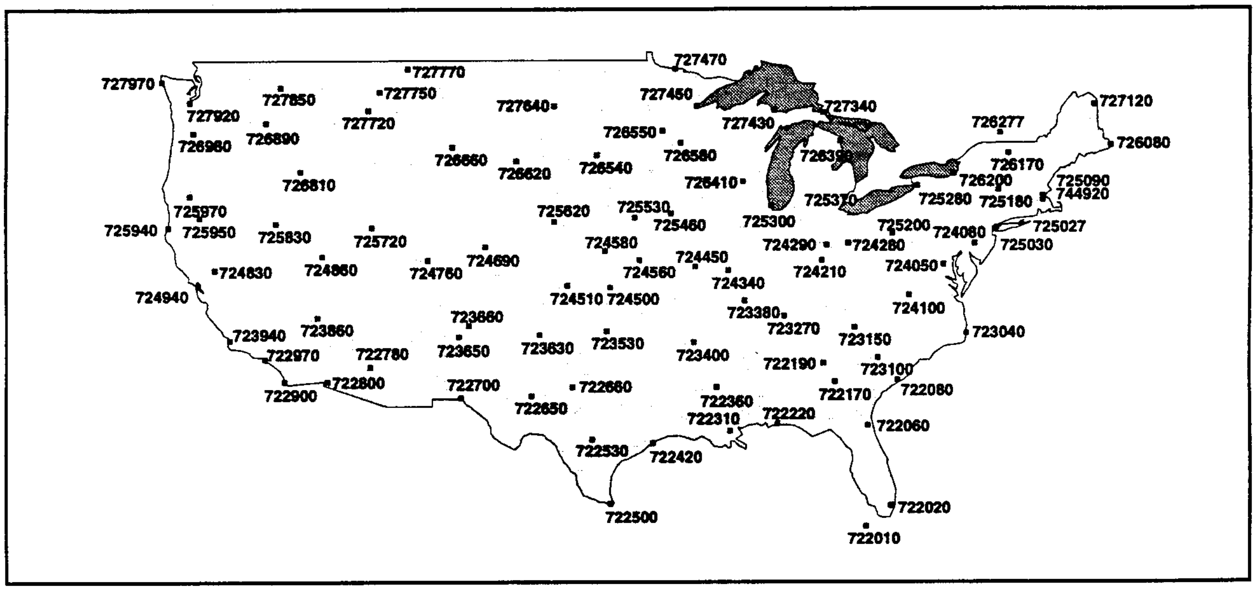

Figure 5-4. Continental U.S. Weather Stations

mand, Control and Communications Network Planner (C3NP) developed by the Command, Control and Communications Systems Directorate. This section describes the NPT communications engineering functions and the NPT process for calculating a link climate factor.

6.1 Communications Engineering

Key communications engineering functions of the C3NP are Network Laydown Planning, Network Connectivity Optimization, and Radio-Frequency-Interference (RFI) Analysis. The LOS propagation reliability model is an integral part of these communications engineering capabilities. The Network Laydown Planner either automatically or manually places communication sites and interconnecting links on the battlefield display. The propagation reliability of every link is calculated using the LOS propagation reliability model. Each link is displayed on a screen with its color assigned according to whether

Table 5-2. U.S. Weather Stations

WMO Number	City	Latitude Deg. N	Longitude Deg. W
700260	Barrow, AK	71.40	156.30
700860	Barter Island, AK	70.10	143.70
701330	Kotzebue, AK	66.90	162.60
702000	Nome, AK	64.50	165.40
702190	Bethel, AK	60.80	162.20
702310	McGrath, AK	63.00	155.60
702610	Fairbanks, AK	64.90	147.70
702730	Anchorage, AK	61.20	149.90
703080	St. Paul, AK	57.10	170.30
703160	Cold Bay, AK	55.20	162.70
703260	King Salmon, AK	58.70	156.70
703610	Yakutat, AK	59.50	139.70
703810	Juneau, AK	58.30	134.40
703980	Annette Island, AK	55.00	131.60
722010	Key West, FL	24.60	81.80
722020	Miami, FL	25.80	80.30
722060	Jacksonville, FL	30.30	81.70
722080	Charleston, SC	32.80	79.90
722170	Macon/Cochran, GA	32.70	83.70
722190	Atlanta, GA	33.70	84.40
722220	Pensacola/Hagler, FL	30.40	87.20
722310	New Orleans, LA	30.00	90.10
722360	Vicksburg, MS	32.40	90.90
722420	Galveston, TX	29.30	94.80
722500	Brownsville, TX	25.90	97.40
722530	San Antonio, TX	29.50	98.50
722650	Midland, TX	31.90	102.20
722660	Abilene, TX	32.40	99.70
722700	El Paso, TX	31.80	106.50
722780	Phoenix, AZ	33.50	112.00
722800	Yuma, AZ	32.70	114.60
722900	San Diego, CA	32.70	117.20
722970	Long Beach, CA	33.90	118.40
723040	Cape Hatteras, NC	35.30	75.70
723100	Columbia, SC	34.00	81.10
723150	Asheville, NC	35.60	82.50
723270	Nashville, TN	36.20	86.80
723380	Cairo, IL	37.00	89.20
723400	Little Rock, AR	34.80	92.30
723530	Oklahoma City, OK	35.40	97.60
723630	Amarillo, TX	35.20	101.70
723650	Albuquerque, NM	35.10	106.60
723660	Santa Fe, NM	35.70	106.00
723860	Las Vegas, NV	36.10	115.20
723940	Santa Maria, CA	34.90	120.50
724050	Washington, D.C.	38.90	77.10
724080	Philadelphia, PA	40.00	75.20
724100	Lynchburg, VA	37.30	79.20
724210	Cincinnati, OH	39.10	84.50
724280	Columbus, OH	40.00	82.90
724290	Dayton, OH	39.90	84.20
724340	St. Louis, MO	38.60	90.20
724450	Columbia, MO	38.80	92.20
724500	Wichita, KS	37.70	97.40
724510	Dodge City, KS	37.80	100.00
724560	Topeka, KS	39.10	95.60
724580	Concordia, KS	39.60	97.70
724690	Denver, CO	39.80	105.00
724760	Grand Junction, CO	39.10	108.50

WMO Number	City	Latitude Deg. N	Longitude Deg. W
724830	Sacramento, CA	38.60	121.40
724860	Ely, NV	39.30	114.90
724940	San Francisco, CA	37.80	122.40
725027	New York, NY	40.70	74.00
725030	New York/LaGuardia	40.80	73.90
725090	Boston, MA	42.40	71.10
725180	Albany, NY	42.70	73.80
725200	Pittsburgh, PA	40.50	80.20
725280	Buffalo, NY	42.90	78.70
725300	Chicago, IL	41.90	87.60
725370	Detroit, MI	42.30	83.10
725460	Des Moines, IA	41.50	93.70
725530	Omaha, NE	41.30	95.90
725620	North Platte, NE	41.10	100.80
725720	Salt Lake City, UT	40.80	111.90
725830	Winnemucca, NV	41.00	117.70
725940	Eureka, CA	40.80	124.20
725950	Mount Shasta, CA	41.30	122.30
725970	Medford, CA	42.40	122.90
726080	Eastport, ME	44.90	67.00
726170	Burlington, VT	44.50	73.20
726200	Oswego, NY	43.50	76.50
726277	Montreal, PQ	45.50	73.70
726390	Alpena, MI	45.10	83.40
726410	Madison, WI	43.10	89.30
726540	Huron, SD	44.40	98.20
726550	St. Cloud, MN	45.60	94.20
726580	Minneapolis, MN	45.00	93.10
726620	Rapid City, SD	44.10	103.10
726660	Sheridan, WY	44.80	107.00
726810	Boise, ID	43.60	116.20
726890	Walla Walla, WA	46.00	118.30
726980	Portland, OR	45.50	122.70
727120	Caribou, ME	46.90	68.00
727340	Sault Ste. Marie, MI	46.50	84.40
727430	Marquette, MI	46.60	87.40
727450	Duluth, MN	46.80	92.10
727470	International Falls, MN	48.60	93.40
727640	Bismarck, MT	46.80	100.80
727720	Helena, MT	46.60	112.10
727750	Great Falls, MT	47.50	111.40
727770	Havre, MT	48.60	109.70
727850	Spokane, WA	47.70	117.40
727920	Olympia, WA	47.00	122.90
727970	Quillayute, WA	48.00	124.60
744920	Blue Hill Observatory, MA	42.20	71.10
911310	Marcus Island	24.30	-154.00
911650	Lihue Kauai, HI	22.00	159.40
911820	Honolulu, HI	21.30	157.90
912170	Guam	13.60	-145.00
912450	Wake Island	19.30	-167.00
912750	Johnston Island	16.70	169.50
912850	Hilo, HI	19.70	155.10
913340	Truk, Caroline Islands	7.40	-152.00
913480	Ponape, Caroline Islands	7.00	-158.00
913660	Kwajalein, Marshall Islands	8.70	-168.00
913760	Majuro, Marshall Islands	7.10	-171.00
914080	Koror, Palau Islands	7.40	-135.00
914130	Yap, Caroline Islands	9.50	-138.00

the reliability exceeds or fails to meet a user-specified link-reliability requirement and whether the link fade margin exceeds a minimum value of 8 dB. The user can manually rearrange the communication assets to provide improved reliability as desired. Alternatively, the user can employ the Network Connectivity Optimizer, which automatically determines the location for a site that maximizes the link reliabilities of all links to this site.

The RFI Analyzer allows the network planner to define and position interference elements within or outside the network. The effect of these interferers is translated into an increased system noise level. This decreases the link reliability by an amount calculated from the propagation reliability model. The LOS propagation reliability model and the associated climate-factor database are crucial to the C3NP communications engineering functions.

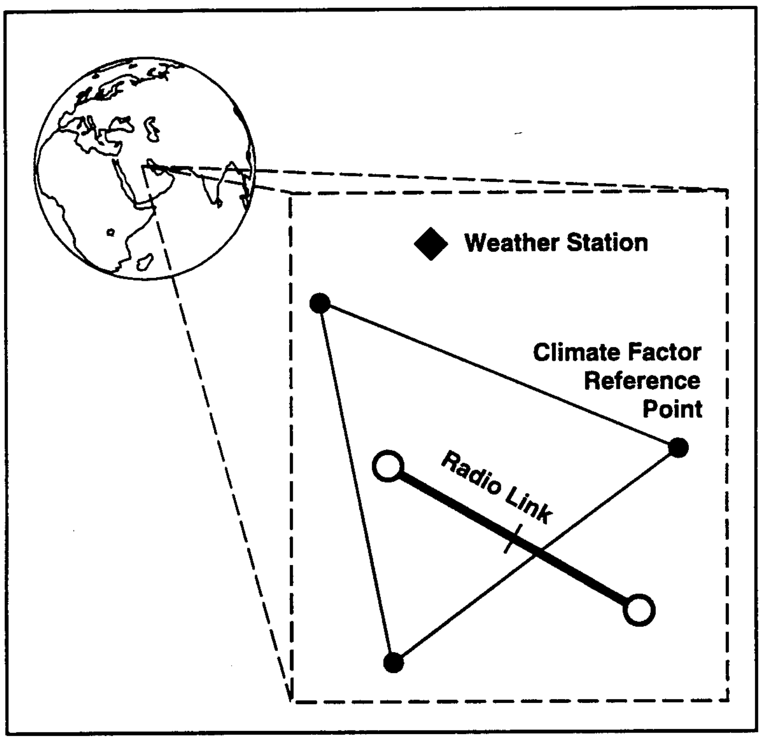

Figure 6-1. Link Climate Factor

6.2 Link Climate Factor Automation

The internal databases in NPT contain values of the annual climate factor at reference points, the reference triangles, and the weather station monthly temperatures that are used in the calculation of monthly climate factors for radio links (Figure 6-1). Monthly climate factor values are computed at time of use. The climate factor values are provided for selected grid points (reference points) on a half-degree latitude-longitude grid, as needed for geographic contour construction during creation of the database. The locations of the reference points have been individually chosen based on geophysical features and the rate of change of the climate factor with respect to geographical position. The climate factor reference points, identified by latitude and longitude, are grouped in triangles (reference triangles) for application in interpolation. The NPT database contains a description of the reference triangles.

The climate factor values at the reference points are based on published annual or worst-month information where available (References 5, 6, and 9). However, published climate factors are not available for a significant portion of the world. The working group has derived climate factors for such cases based on world charts of refractivity gradients (Reference 8), geophysical features, temperature records, and unpublished information from subject matter experts (where available).

Monthly average temperatures at a reference point are those at the nearest weather station, as measured by distance along a great circle, from a worldwide set of weather stations. The source of the monthly temperature values is a world weather database (Reference 10). The monthly averages are generally based on at least 15 years

of measurements beginning no earlier than 1960. In some cases, fewer than 15 years are used when a full set of data is not available. Averages containing fewer than 15 years arise when measurements have not been made or measurements for certain months are not available, in which case the entire year is omitted from the average.

The NPT automatically provides the monthly climate factor for an LOS link, using the following steps. Center coordinates of a link are used to find a reference triangle that contains the coordinates (Figure 6-1). The monthly climate factors are calculated for each of the three reference points using the associated monthly temperatures. The monthly climate factor for the center of the link is obtained by three-dimensional linear interpolation, using a plane defined by the three points.

7. Conclusions

In summary, the climate-factor modeling effort of the working group has had both operational and research impact. Operationally, the Army now has a new capability for propagation-reliability planning and engineering of LOS communication links for deployment anywhere in the world. From a research standpoint, climate factor investigation has been stimulated as a result of the tactical need for worldwide monthly climate factors.

8. References

1. K. H. Brockel et al., Tactical Line-of-Sight Radio Propagation Reliability, CECOM Technical Report TR-91-3, October 1991.
2. K. H. Brockel and A. Vigants, "Line-of-Sight Radio Fading Prompts Remedial Program," *SIGNAL*, November 1992, pp. 63-65.
3. K. D. Chaney et al., Tactical Line-of-Sight Path Reliability: Improved MSE System Procedures, CECOM Technical Report TR-92-1, April 1992.
4. F. G. Loso et al., "U.S. Army Tactical LOS Radio Propagation Reliability," DARPA Tactical Communications Conference, Fort Wayne, Indiana, April 1992.
5. T. Tjelta et al., "Systematic Development of New Multivariable Techniques for Predicting the Distribution of Multipath Fading on Terrestrial Microwave Links," *IEEE Trans. Ant. Prop.*, Vol. 38, No. 10, pp. 1650-1665, October 1990.
6. R. L. Olsen and B. Segal, "New Techniques for Predicting the Multipath Fading Distribution on VHF/UHF/SHF Terrestrial Line-of-Sight Links in Canada," *Can. J. Elect. & Comp. Eng.*, Vol. 17, No. 1, pp. 11-23, 1992.
7. A. Vigants, "Space-Diversity Engineering," *The Bell System Technical Journal*, Vol. 54, No. 1, pp. 103-142, January 1975.
8. B. R. Bean et al., A World Atlas of Atmospheric Radio Refractivity, ESSA Monograph 1, U.S. Government Printing Office, 1966.
9. G. N. Elkhouri et al., LOS Link Design Model Enhancements, Technical Report prepared for the Defense Communications Engineering Center by AT&T Bell Laboratories, November 1989.
10. World WeatherDisc, CD-ROM, WeatherDisc Associates, Inc., Seattle, Washington.

9. Acronyms

The following acronyms have been used in this report:

C3NP	Command, Control and Communications Network Planner
C3SD	Command, Control and Communications Systems Directorate
CECOM	U.S. Army Communications-Electronics Command
ECAC	Electromagnetic Compatibility Analysis Center
LOS	Line of Sight
MSE	Mobile Subscriber Equipment
NPT	Network Planning Terminal
RFI	Radio Frequency Interference
WMO	World Meteorological Organization.